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BUCKLING STRENGTH OF COMPRESSED COLUMNS USING DESIGN RULES AND NONLINEAR STABILITY ANALYSIS

PEVNOST VE VZPĚRU SLOUPŮ NAMÁHANÝCH TLAKEM S POUŽITÍM PRAVIDEL DESIGNU A NELINEÁRNÍ ANALÝZY STABILITY

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Abstract

In this paper results of column critical loads calculations obtained by design rules for beam stability and by nonlinear analysis are compared. Design rules DNV and BAS/JUS are used to compare with results of nonlinear analysis. Nonlinear analysis is done by using Finite Element Method through ANSYS software. For imperfection modelling standard tolerances for column discrepancy from ideal straight-line shape are used. Initial standard allowed curvature by using transversal force is introduced to the finite element model. Results for column with pinned-pinned boundary conditions are shown.

KEY WORDS: buckling, strength, ANSYS software

1. Introduction

Columns are one of the most used elements in many engineering constructions. Their specific geometry may cause failure because of stability loss rather then failure because of exceeding stress in an elastic domain. It could appear in a load case, which includes axial compression. Analyst is facing the problem of critical load calculation, which exceeding causes large deformation (Fig. 1-b). Analytical solutions exist for different boundary conditions, but it could be used for ideally straight columns only. In practical applications imperfections are unavoidable, and columns behave as shown in the Fig.1-c. Column design could be checked applying nonlinear analysis, using into account possible imperfections, or applying corresponding design rules.

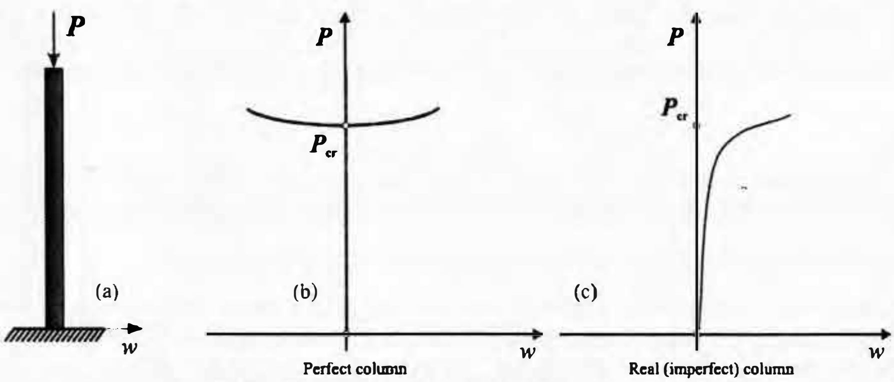


Fig. 1 Ideal and real and behaviour of compressed column.

In this paper results of column critical loads calculations obtained by design rules for beam stability and by nonlinear analysis are compared. Design rules DNV and BAS/JUS are used to compare with results of nonlinear analysis. Nonlinear analysis is done by using Finite Element Method, which is implemented through ANSYS software. For imperfection modelling are used standard tolerances for discrepancies from straight-line shape, given by DIN and ISO standards.

Initial imperfection, allowed by standard rules, is introduced by exerting of transversal force. Required value of transversal force is calculated from corresponding linear expression for displacements of bended beam. Results of nonlinear analysis of a column with pinned-pinned boundary condition for all standard imperfection classes are given and compared with used design rules for considered column.

2. Buckling load calculation by design rules

Calculation of critical buckling load is based on the column slenderness, which is defined as

$$\lambda = \frac{\lambda_k}{\pi}\sqrt{\frac{\sigma_Y}{E}} \tag{1}$$

where σ_Y is yield stress, E is Young modulus of elasticity and λ_k is critical slenderness. Critical slenderness is defined by

$$\lambda_k = KL\sqrt{\frac{A}{I}} \tag{2}$$

where L is column length, A is cross sectional area, I is moment of inertia and K is effective length factor depending on boundary condition. Theoretical and recommended value of effective length factor K for six possible boundary condition are given in the Table 1.

Tab 1 Effective length factor, theoretical and recommended value.

Boundary conditions						
Theoretical value	0.5	0.7	1.0	1.0	2.0	2.0
Recommended design value	0.6	0.8	1.2	1.0	2.1	2.0

Using column slenderness, critical buckling stress for perfect column is then given as

$$\frac{\sigma_{cr}}{\sigma_Y} = \frac{1}{\lambda^2} \tag{3}$$

For a real column, critical buckling stress is given through appropriate diagrams, which is for a column with a symmetric cross-section made of construction steel given in the Fig. 2.

3. Buckling load calculation by nonlinear analysis

Buckling load calculation by nonlinear analysis by finite element method is performed. Nonlinear calculation is implemented using ANSYS software. It is assumed axially loaded real column, which could initially differ from the straight line shape. Initial discrepancy from ideal straight line shape is used according DIN and ISO standards. These avoidable discrepancies are given in the Table 2 for length L = 2000 mm.

Imperfection is introduced in the finite element model by adding transversal force (Fig. 2-a) which acting produces discrepancy from straight line shape. Required intensity of transversal force F is calculated from the linear dependency of maximum transversal displacement $w_0 = f(F)$, which is, e.g. for a pinned-pinned beam, given by

$$w_0 = \frac{FL^3}{48EI} \tag{4}$$

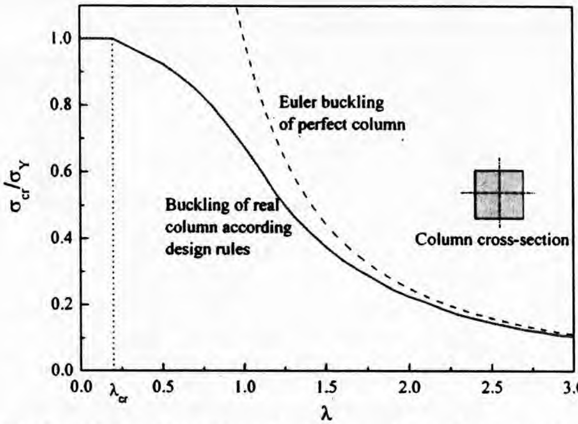


Fig. 2 Critical buckling stress for column according design rules and Euler.

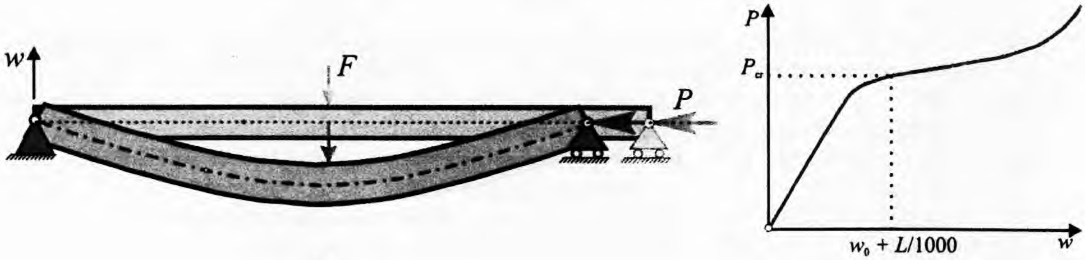
Tab. 2 Imperfections according DIN and ISO standards for length L = 2000 mm.

DIN		ISO	
Class	w_0	Class	w_0
S	0.2	H	0.4
T	0.6 mm	K	0.8 mm
U	2.5 mm	L	1.6

Increasing of a axial load P for constant transversal force F, equilibrium path is calculated (Fig. 2-b). Because of initial discrepancy of the straight line shape, additional lateral displacements appears even axial force P is smaller than critical. These displacements are small until axial force is near critical value, when large displacements appear. In this paper critical value of axial force is used when maximum lateral displacement w, consisted of initial imperfection and displacement caused by axial force, becomes equal to

$$w = w_0 + \frac{L}{1000} \tag{5}$$

where value $L/1000$ is used as limit displacement in many engineering applications.



(a) (b)

Fig. 3 Imperfection modeling (a); and critical load determination from resulting equilibrium path (b).

4. Results analysis

The results of nonlinear buckling load analysis of imperfect pinned-pinned column are shown in the Fig. 4. The value of critical axial force is determined for all classes given in the Table 2. and compared with the design rules recommendations, shown in the Fig. 2.

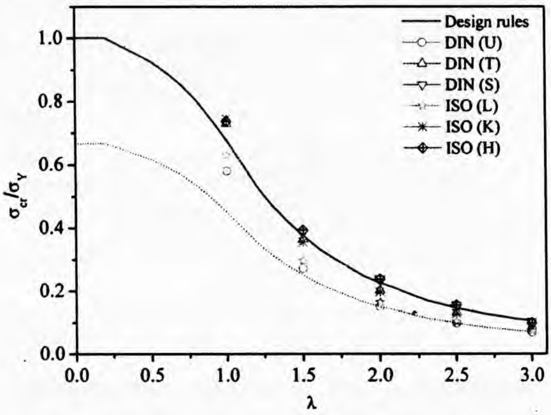


Fig. 4 Critical buckling stress for pinned-pinned column defined by design rules and nonlinear analysis of imperfect column.

The results show that critical buckling load for imperfect column calculated by nonlinear analysis well agree with design rules. Only for DIN class U and ISO class L nonlinear analysis predicts value of critical buckling load smaller up to 1.5 times then in design rules, and could be covered by safety factor of 1.5 (dot-line).

5. Conclusion

Results for buckling load for imperfect column, calculated by design rules and nonlinear analysis, are presented. For buckling load in nonlinear analysis is used load for which maximum displacement exceeds 1/100 of column length. Imperfection of column is used according ISO and DIN rules. Results agrees well for all for classes S and T of DIN and H and K of ISO. Difference appears for classes with maximum allowed discrepancy from ideal shape, U of DIN and L of ISO, where buckling load is less 1.5 times then in case of design rules.

Acknowledgement

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References

[1] THOMPSON, J.M.T., HUNT, G.W.: *A General Theory of Elastic Stability*, John Wiley & Sons, New York, 1973.

[2] COOK, R., MALKUS, D.S., PLESHA, M: *Concepts and Application of Finite Element Analyses*, John Willey & Sons, New York, 1988.

[3] ISIĆ, S., DOLEČEK, V., KARABEGOVIĆ, I.: In: Proceedings of the 12th International Conference on Problems of Material Engineering, Mechanics and Design, 2007, Jasna, 121.

[4] Det Norske Veritas (DNV), Buckling Strength Analysis Of Bars And Frames, And Spherical Shells, CN 30.1, 2004.

[5] BAS/JUS U.E7.081/1986, Centrically compressed columns of constant cross-section.

[6] BAS/JUS U.E7.096/1986. Columns exploited to bending and compression.

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